P-15

Study of the surface microrelief of copper nanoparticles by the method of scanning probe microscopy

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Studies of the microrelief (morphology and surface roughness) of the copper nanoparticles, heat treated glass substrates coated with ITO layer was carried out using scanning probe microscopy mode atomic force microscopy. The investigated samples are characterized by the presence of an uneven surface consisting of spherical copper particles with dimensions in the range from 30 to 110 nm in the organic matrix of the surfactant.

At present, copper nanoparticles (copper NPs) are one of the promising materials for the creation of functional films with high electrical conductivity for devices of micro- and nanoelectronics [1]. Methods of obtaining such particles are given much attention [2,3] as comparison with the study of their surface microrelief. Such a parameter as the surface roughness affects the quality and performance of the various instruments and devices. Therefore, depending on the further functional purpose of the film with copper NPs, it must meet certain requirements. For example, when obtaining high-conductivity films, the conditions for their sputtering or self-assembly must be selected in such a way that the surface roughness is minimal and uniform throughout the sample. This is necessary to reduce the losses associated with the scattering of charge carriers at the inhomogeneities, film defects, etc. When creating coatings of parts operating under conditions of constant friction, the roughness should be of the order of several micrometers.

The morphology and surface roughness of copper NPs on glass substrates with an ITO layer (Indium Tin Oxide) were studied by scanning probe microscopy (AFM) in atomic force microscopy (AFM) modes using the Nanoeducator II (NT-MDT, Russia). AFM images of the surface of copper NPs film (top view) and its profile (Fig.1a and b, respectively) were obtained. The processing of AFM images was carried out using the Gwyddion program. The synthesis of copper NPs was carried out by chemical reduction in an aqueous solution of an anionic type surfactant — sodium dodecyl sulfonate (SDS) ($C_{12}H_{25}SO_4Na$), according to the previously developed procedure [4]. The acidity of the medium was pH = 11.2 at molar ratio of the precursor ($CuCl_2 \cdot 2H_2O$) and the reductant (hydrazine) equal 1:150. Before applying of the solution with copper NPs to solid substrates resulting suspension sample preparation was carried out by centrifugation and decantation of the solution to remove excess surfactant. After the centrifuged solution was taken from the bottom of a micro test-tube eppendorf type and applied to a substrate. Then it was heated for 5 minutes at 100 °C.

The obtained AFM images of the surface microrelief of the sample show the presence on the substrate of glass with ITO layer spherical copper particles. The particles coated with a surfactant have a size in the range from 30 to 110 nm. From Figure 1a it can be seen that the copper particles are uniformly distributed over the surface of the substrate. The change in color contrast of the surface and the extracted profile of the surface of the test sample (Fig. 1b) indicate the presence of defects in the resulting film. They are visualized in the form of depressions and protrusions of various depths, heights and widths. The profile of the surface roughness along lines 1 and 2 extracted along of the investigated sample shows that in regions 1 and 2 the average maximum roughness height is 46 nm and 28 nm. The average maximum depth of the roughness cavity is 51 nm and 22 nm, respectively. A significant difference in the obtained results along lines 1 and 2

may be due to the effect of thermal treatment of the substrate on the distribution of the suspension with copper NPs on its surface and with aggregation of particles.

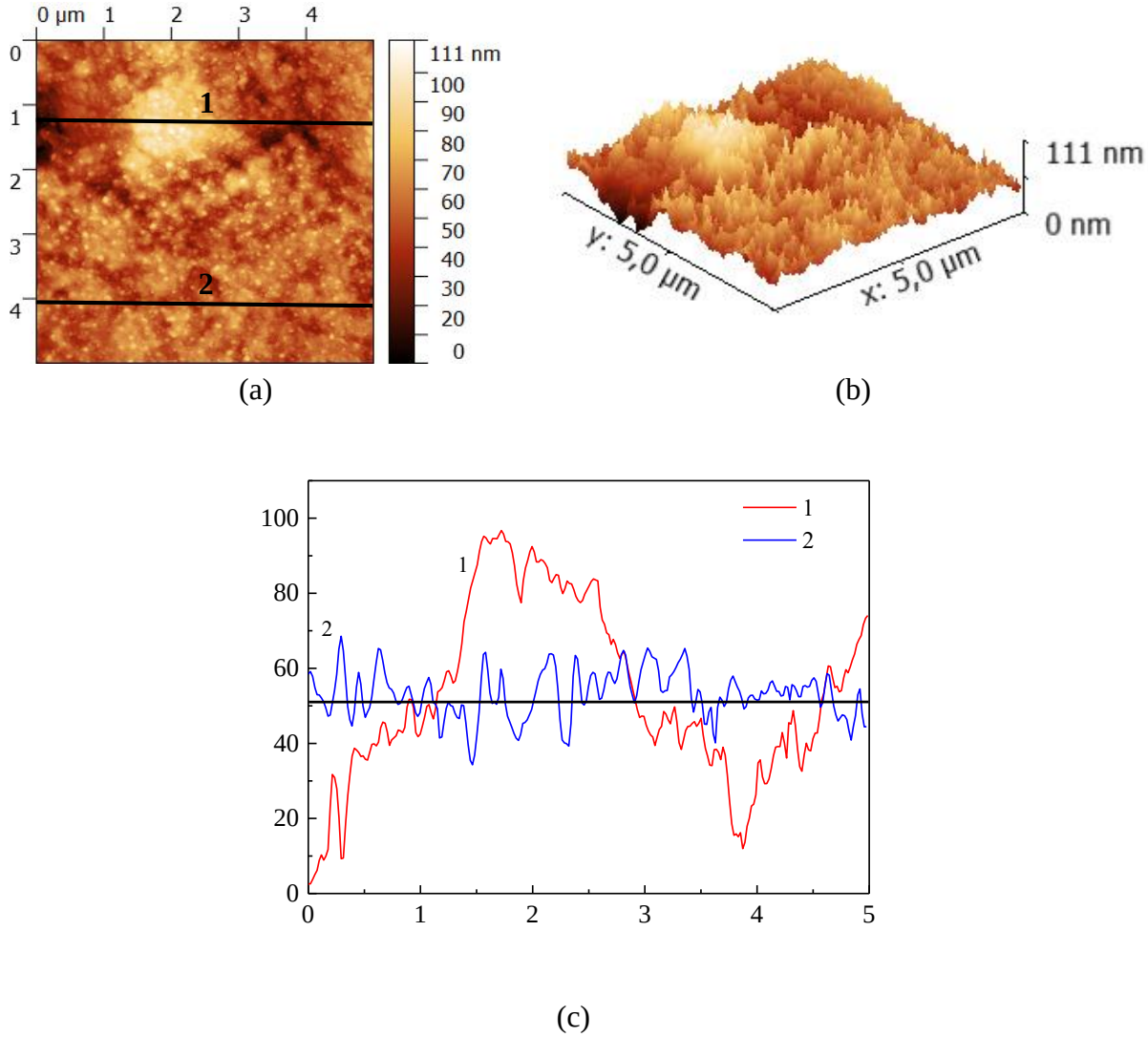

Figure 1. AFM images: (a) morphology (top view) and (b) surface profile (side view), (c) surface roughness of copper nanoparticles on a glass substrate with ITO layer (1, 2 – surface roughness areas of the sample).

Thus, it is shown that when the substrate with copper nanoparticles is thermally treated, an uneven surface microrelief can be formed with differences of the mean maximum height and roughness depth in the ranges from 28 to 46 nm and 22 to 51 nm, respectively.

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